FINAL REPORT

RESEARCH AND DEVELOPMENT
ON
PAPER DIELECTRIC CAPACITORS

Contract No. DA-36-039-sc-42485
File No. 11633-PH-52-91
United States Signal Corps

31 December 1953

SPRAGUE

SPRAGUE ELECTRIC COMPANY
North Adams, Mass.

CORRECTION

TO

FINAL REPORT

Contract No. DA-36-039-sc-42485

TABLE 18

COMPARISON OF CAPACITOR SIZES

Comparisons are stated in terms of capacitance per unit volume of the uncased capacitor section (microfarads per cubic inch). Room temperature capacitance values are employed.

			Microfarads per Cubic Inch	
Impregnant	Voltage Rating	High Ambient Temperature	Capacities Below 0.1 mfd	Capacities Above 0.5 mfd
(Paper-foil Capacitors)				
Halowax	200VDC	+85°C	1.5	2.6
Purified Lanosterol	200VDC	+85°C	1.8	3.1
Vitamin Q	600VDC	+125°C	0.4	0.7
Purified Lanosterol	600VDC	+85°C	0.7	1.2
(Metallized Paper Capacitors)				
Mineral Wax	200VDC	+85°C	4.3	7.2
Purified Lanosterol	200VDC	+85°C	5.9	9.8
90% Purified Lanosterol + 10% Castor Oil	200VDC	+85°C	6.0	10.2

SPRAGUE ELECTRIC COMPANY

NORTH ADAMS, MASSACHUSETTS

COPY NO. 22

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51-65 Sprague Electric Company

SPRAGUE ELECTRIC COMPANY

NORTH ADAMS, MASSACHUSETTS

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PURPOSE

This contract is concerned with the investigation, application and evaluation of lanosterol and lanosterol mixtures as impregnants in paper and metallized paper dielectric capacitors. The intent is to approach the requirements of MIL-C-25A, Characteristic F, with an allowable dissipation factor of 2%. The maximum rating will be 600 volts d.c., and the temperature range of operation will be from -55°C to +85°C.

SUMMARY

Extensive investigations have been made concerning the nature of lanosterol and lanosterol impregnated capacitors.

The physical properties of lanosterol were determined.

A chemical analysis of commercial lanosterol was performed.

An investigation of the purification of lanosterol was carried out, and a method was adopted whereby the lanosterol was recrystallized from low boiling solvents.

A large batch of lanosterol was purified on a semi-production scale. The product was electrically equivalent to that purified in the laboratory.

The effect of various additives on the electrical properties of lanosterol was observed. Castor oil was selected as an additive for the lanosterol impregnant.

The electrical properties of commercial lanosterol were examined and were found to vary from batch to batch.

Other effects peculiar to the lanosterol dielectric were examined.

Paper-foil and metallized paper capacitors utilizing variations of the lanosterol impregnant were manufactured and evaluated. On the basis of these results, sample capacitors were produced for shipment to the S.C.E.L., Fort Monmouth, New Jersey.

CONFERENCES

1. 25 June 1952 with Botany Mills at Passaic, New Jersey. Botany's method of production and purification was discussed.
2. 6 August 1952 with SCEL at Fort Monmouth, New Jersey. The work to that date was reviewed, and the program for the immediate future was presented. The modification of lanosterol with additives was discussed. It was mentioned that if 125°C proved too severe, that an interest existed for an 85°C capacitor.
3. 19 August 1952 with SCEL representatives at the Sprague Electric Company, North Adams, Massachusetts. The work to that date was reviewed.
4. 9 September 1952 with SCEL at Fort Monmouth, New Jersey. The contract work on lanosterol was presented before the Sub-Panel on Capacitors of the Research and Development Board.
5. 6 March 1953 with SCEL at the Sprgaue Electric Company, North Adams, Massachusetts. The work to that date was reviewed. It was agreed to manufacture and test not more than 36 capacitors impregnated with commercial lanosterol. The need for a time extension on the contract was discussed.
6. 19 May 1953 with SCEL at the Sprague Electric Company, North Adams, Massachusetts. The announcement that Botany Mills had ceased production of lanosterol was discussed. It was agreed that the project would be continued.
7. 10 September 1953 with SCEL at Fort Monmouth, New Jersey. The work to that date was reviewed. The types and numbers of sample paper foil capacitors was agreed upon.

SECTION I - INTRODUCTION

Lanosterol is of interest as a capacitor impregnant because of its high dielectric constant at room temperature. The obvious possibility is a reduction in the size of a capacitor which utilizes this material as the impregnant. However, the high negative temperature coefficient of lanosterol limits this apparent advantage, since there is a considerable decrease in dielectric constant at the high and low temperature extremes.

This investigation was concerned with the electrical properties of lanosterol, possible improvements in these by purification of the lanosterol, and/or modifications by the use of additives.

The original aim of the contract was to pass Characteristic "E" of JAN-C-25 with the high ambient temperature extended to 125°C. Results of the First Quarterly Report demonstrated the improbability of capacitors impregnated with lanosterol meeting these standards. Consequently, a modification of the Technical Requirements was made so that the new goal was Characteristic "F" of JAN-C-25 including an allowable dissipation factor of 2% at room temperature (Appendix, page 31).

SECTION II - GENERAL DISCUSSION

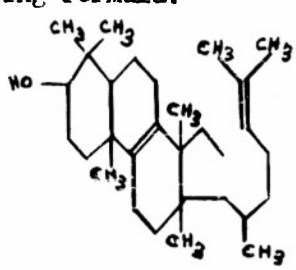
A. Source of Material

Lanosterol is a constituent of wool fat. The only recent supplier of lanosterol in North America has been Botany Mills, Inc., Passaic, New Jersey. They were producing only pilot plant quantities (ca. 14 pounds per week), but at present even this production has been suspended (Appendix, page 33). If it became economically feasible, Botany Mills could reopen its processing facilities and could substantially increase its production of lanosterol. The potential U. S. manufacturing capacity of lanosterol from wool fat is in excess of one million pounds per annum.

Botany Mills obtaines lanosterol from the lanolin alcoholic fraction of lanolin [1]. Lanosterol has been shown to be identical to the compound cryptosterol which is derived from yeast [2]. This presents another possible source of the material

B. Chemical Nature

Lanosterol is a chemical species with the empirical formula $C_{30}H_{50}O$. Much work has been done towards elucidating the physical structure and orientation of the lanosterol molecule, especially by the English School of Doree and McGhie, and by the Swiss School of Ruzicka. One of the more recent papers of the latter [3] favors the following formula:



It was found that this structure cannot be dissected into simple isoprene residues, and thus the original belief in the triterpenoid nature of lanosterol has been discarded. Lanosterol is not a sterol, and the nomenclature is misleading.

The positions of the OH group of the double bonds in the above configuration have been corroborated by other investigators [2,5].

C. Physical Properties

The product supplied by Botany Mills is described in their data sheets (Appendix, page 34). In the crystal form, lanosterol is a soft, white flake. The pure material melts at 141-142°C. The commercial product melts ca. 120-130°C, and is apparently more impure than that described in the data sheet (m.p. 138°C). On cooling, the molten material forms a hard, brittle, semi-transparent solid with a dark amber color. After extended purification, the material exhibits a more transparent nature and a much lighter color. The lanosterol darkens upon exposure to heat, indicating a sensitivity to high temperatures. The presence of a reactive double bond in the molecular structure of lanosterol may account for this sensitivity to heat.

The specific gravity of lanosterol was determined at various temperatures [7]. The specific gravity was 1.03 at 20°C and 0.93 at 150°C (Table 1). These data were necessary in the calculation of the dielectric constant from capacity measurements on large solid discs of material. Also, this information was useful in estimating the amount of lanosterol necessary for further work.

The viscosity of molten lanosterol was determined at various temperatures with a Brookfield Electroviscometer [7]. The viscosity of commercial lanosterol was 34.5 centipoises at 148°C (Table 2). It is generally desirable to have an impregnant with a viscosity of less than 100 centipoises for vacuum impregnation.

Although purification had caused the viscosity to rise somewhat, the value at 150°C was satisfactory for impregnation at that temperature.

X-ray diffraction patterns of various varieties of lanosterol were obtained [7]. They showed that all varieties had, at least in part, a crystalline nature.

D. Physiological Effects

The personnel at Botany Mills who have been working with lanosterol for a number of years have noticed no toxic effects or allergenic sensitizations due to this material. They have observed no special precautions in the handling of lanosterol. Our experience, which at times involved intimate handling and exposure to vapors, confirms the Botany report.

Some persons have exhibited a hypersensitivity to lanolin resulting in a contact-type dermatitis. The responsible allergen, however, is not present in either the lanosterol or the cholesterol fractions of lanolin [6].

E. Analytical Results

Botany Mills disclosed that the lanosterol which they supply melts at 138°C and contains ca. 2% aliphatic lanolin alcohols and ca. 2% cholesterol. They did not reveal their methods of analysis. It was found that the melting range of the commercial lanosterol was 120-130°C. This seemed to indicate a greater amount of impurities than was reported to us.

An attempt was made to analyze the amount of cholesterol present as an impurity by a gravimetric method utilizing a digitonin addition product [7]. The results, which have been inconsistent, indicated the presence of ca. 7.3% cholesterol. Analysis of lanosterol to which 9% cholesterol had been added resulted in a value of 16.1% cholesterol [7]. After purification the amount of cholesterol dropped to 2.3%.

The saponification number and acid number of lanosterol were determined [7]. Before purification of the lanosterol, the saponification number indicated the presence of 3.5-6.5% of esters of an assumed molecular weight of 500. After purification the amount fell to 2.6-3.2%. The total acid number before purification showed the presence of 1.3-1.5% of acids of an assumed molecular weight of 375. After purification, the value dropped to 0.1-0.2% (Table 3).

The ash content of commercial lanosterol was found to be of the order of 0.2%. The aqueous extract of lanosterol contained chloride, sulphate, and calcium ions in trace amounts (Table 3).

SECTION III - PURIFICATION OF LANOSTEROL

A. Introduction

Commercial lanosterol demonstrated properties which were below the conventional standards for capacitor impregnants [7]. The material exhibited a large decrease in dielectric constant at the temperature extremes. In addition, the resistivity was quite low at the high temperatures, and the dissipation factor was unsatisfactory throughout the temperature range.

It was obvious that lanosterol impregnated capacitors would not approach the original goal, i.e. Characteristic "E" of JAN-C-25, with the high ambient temperature extended to 125°C. It was decided that the revised requirement, Characteristic "F" [8], would be met more satisfactorily if commercial lanosterol were purified.

Thus, purification of the lanosterol was undertaken. The original aim of the purification program was a product with a sharp high melting point, approaching that cited in the literature for the pure compound (142°C). It was assumed that such a product would have the most desirable electrical properties. Although this was found to be true, the melting point was an insufficiently sensitive criterion of degree of purity. Thus, the direct measurement of electrical properties of lanosterol was adopted. This method utilized a 50 mmfd air condenser immersed in the molten impregnant in a 100 ml beaker. The subsequent measurement of electrical properties, unlike the determination of melting point, was sufficiently sensitive to small improvements in the purity of lanosterol.

B. Methods of Purification

The most desirable method of purifying the lanosterol from a production standpoint is filtration from an adsorptive medium. Filtration of electrical-grade oils and waxes is standard practice in the capacitor industry. Two commonly used adsorbents are Attapulgus Clay (Fuller's Earth) and an activated bentonite clay (Retrol Earth). Molten lanosterol was filtered in the presence of each of these adsorbents [7]. Increases in the resistivity of lanosterol at 150°C occurred in both cases, with Retrol Earth proving more effective. Repetitive filtrations were even more beneficial [7,8]. However, the products had variable physical and electrical properties which could not be reproduced. Degradation of the lanosterol was probable taking place. Furthermore, the yield of material was prohibitively low.

The other general method of purification which was investigated consisted mainly of recrystallization of lanosterol from its acetone solution. Methanol was used to effect precipitation. After a program of experimentation, the above purification procedure was adopted. Both an initial water wash and the use of Retrol Earth adsorbent during solution in the acetone caused improvement of the electrical properties of lanosterol and were incorporated in the purification procedure [7].

This method of purification produced a material which was considered to be satisfactory for the purposes of the contract. The electrical properties of this material were found to be consistently reproducible.

Repetitive (3X) recrystallization produced still better electrical properties. However, there was only a 30% yield as a result of the cumulative losses. Also, the considerable increase in time, labor, and the cost of materials showed this procedure to be impractical.

Table 4 summarizes the electrical properties of lanosterol purified according to these various procedures.

C. Pilot Plant Purification

It was necessary to set up an operation for the purification of the relatively large amount of lanosterol (140 lbs.) required for the latter phases of the program. With the use of equipment and facilities available at the Sprague Electric Company, a pilot plant was designed and constructed for the necessary processing [8]. A flow sheet of the process is shown in Figure 1.

The steps of the purification procedure are as follows:

1. The entire batch of lanosterol was agitated for one hour in ten parts of boiling distilled water.
2. The solid was collected in a centrifuge and dried in air at room temperature. (The lanosterol was divided into three batches, and the remainder of the purification was performed on each batch.)
3. The lanosterol was dissolved in 18 parts of boiling acetone in the presence of 10% retrol adsorbent.
4. The retrol was removed from the hot solution by filtration.
5. Two parts of methanol were added to the solution.
6. When the resultant slurry had cooled, the lanosterol precipitate was collected by filtration and dried in air.
7. The three batches of purified material were mixed together.

The product of this pilot plant purification of lanosterol was found to be satisfactory for the purposes of the contract. Measurement of various samples of this material showed a consistency in electrical properties. These properties were equivalent to those of lanosterol purified in the laboratory (Table 5) [10].

If this variety of purified lanosterol were found to be useful on the industrial level as an impregnant for capacitors, a more practical process for purification could be designed. For example, a continuous process would be less expensive to operate that the previously described batch process. The inclusion of the recovery and reuse of solvents and lanosterol from the waste liquor in a continuous process would then be possible. Even so, the problem of the deterioration of lanosterol would still be present. Because of this effect of heating, it would be necessary to repurify the material after each impregnation. In a continuous process, this could be accomplished by the systematic introduction of controlled amounts of used impregnant. The resulting product would then have reasonably consistent properties.

If the impregnant were required to contain an additive, such as castor oil, repurification would become a more involved problem. Additional steps in the purification process probably would be needed to remove the additive prior to repurification. The process would perhaps not then be feasible from an economic standpoint.

An ideal solution to this overall problem would be the control of deterioration, if possible. This, however, would necessitate a program of experimentation and evaluation. If deterioration could be controlled, the lanosterol could be reused, and only occasional repurification would be required. Thus, the amount of raw materials and processing would be reduced to a minimum, and a simple batch process could be employed for purification.

SECTION IV - ELECTRICAL EVALUATION OF THE LANOSTEROL DIELECTRIC

A. Variations in Commercial Lanosterol

Samples of the various batches of lanosterol were tested for electrical properties by means of the 50 mmfd cell method (Section III-A, page 9). Results of these tests indicated a variation in the degree of purity of commercial lanosterol [9]. This is understandable, since only a small change in the amount of some impurities (e.g., aliphatic alcohols) could result in a relatively large change in resistivity. For example, lanosterol sample L-3 had a resistivity of 3.1×10^9 ohm-cm at 150°C, while that of L-4 was 7.3×10^9 ohm-cm (Table 6). This spread was carried over to the purified samples [2]; L-3: 25×10^9 ohm-cm, L-4: 80×10^9 ohm-cm. Thus, it was necessary to use the same starting material in order to obtain a proper evaluation of capacitors impregnated with lanosterol. A sample of the final batch of lanosterol (L-5) was tested and was found to be somewhat inferior to all previous samples received from Botany Mills.

B. Lanosterol Plus Additives

Mixtures of castor oil and lanosterol were reported to have higher dielectric constants at room temperature than lanosterol alone [12]. An investigation of the effect of castor oil and of other additives on the electrical properties of lanosterol has been made in this laboratory [7].

The reported increases in the dielectric constant of the castor oil mixtures have been observed only in the near room temperature range. This increase resulted in a greater capacitance change at the temperature extremes. The resistivity of lanosterol was found to decrease with increasing castor oil content. If a 125°C capacitor were desired there would be little advantage in using castor oil as an additive to the lanosterol impregnant.

The effect on lanosterol caused by the addition of various other materials was examined [7]. None of these additives produced any desirable effects on the resistivity and dissipation factor of lanosterol.

C. Deterioration

On heating lanosterol, an apparent degradation was noticed at the very outset of the contract [2]. This effect occurred even at relatively moderate temperatures [7]. For example, a sample of lanosterol was heated in air at 80°C. A comparison sample was allowed to remain at room temperature. The effect on the melting point was as follows:

Time Elapsed In Hours	Melting Point Room Temp. Sample	Melting Point Oven Heated Sample
20	133.5 - 135°C	133.5 - 135°C
60	133.5 - 135°C	103 - 112°C

These data show that heating lanosterol caused its melting point to be lowered. It is reasonable to assume that this degradation would occur faster and to a greater extent at 150°C, at which temperature all impregnations were performed.

The resistivity of both purified and unpurified lanosterol fell to less than one-half of their original values after about 20 hours at 150°C. After 80 hours, the values had fallen to about one-fifth of the starting values. A sample heated in vacuum behaved similarly after 20 hours, but the resistivity declined only slightly from this value after 80 hours (Figure 2).

Samples of lanosterol purified by various methods were examined for deterioration of electrical properties after having been maintained at 150°C in air for 5 hours. (Five hours are required for the total impregnation cycle.) The sample purified by the recrystallization method which had been adopted for all purification, showed the least decrease in resistivity during that time [8].

No further analysis of this heating effect was performed. In order to minimize this effect, the impregnant was continuously maintained under vacuum during impregnation, even before the lanosterol has melted. Dry nitrogen was used to break the vacuum.

D. The Slow Cooling Effect

It has been reported that a change in the dielectric constant of lanostero occurred when the material is cooled at a slow rate [12]. This effect has been investigated for commercial lanosterol and lanosterol purified by the recrystallization method. Changes in the dielectric constant of these samples were in general agreement with the reported results [7]. Lanosterol purified by repetitive hot adsorptive filtration did not exhibit this effect (Table 7).

The changes of dielectric contant due to slow cooling could be a manifestation of a varying degree of crystallinity. Thus, the differences in results between unpurified lanosterol and that purified by the adopted procedure are understandable, since the impurities could well affect the rate and degree of crystallization. The material purified by adsorptive filtration had acquired different physical (and probably chemical) characteristics due to the extended exposure to high temperature. Thus, it may have acquired a completely different crystalline structure.

SECTION V - EVALUATION OF PAPER-FOIL CAPACITORS

A. Design and Manufacture

All test capacitors were designed to have a capacity of one microfarad. The design constants for lanosterol were obtained from data recorded in the First Quarterly Report.

The capacitor sections were "inductively" wound. The sections were encased in hermetically sealed metal cans. One terminal was grounded to the can. The other terminal was brought out through an eyelet mounted in a glass-kovar end seal.

The impregnation of the capacitors was performed according to special techniques [10]. The impregnation temperature was 152°C. Special provisions were made to maintain the lanosterol under vacuum or nitrogen during the entire procedure in order to minimize deterioration of the impregnant.

Three varieties of the lanosterol impregnant were used to manufacture the test capacitors: commercial lanosterol, purified lanosterol, and the mixture of 90% purified lanosterol and 10% castor oil

B. Variation of Electrical Properties with Temperature

It was desired to meet the Characteristic "F" requirements for insulation resistance and capacitance change, and to maintain a dissipation factor of less than 2% at room temperature. The properties of paper foil capacitors impregnated with commercial lanosterol, purified lanosterol and the mixture of 90% purified lanosterol and 10% castor oil all met the above requirements [11].

The properties of the purified lanosterol capacitors were, in general, superior to those of the other two impregnants (Table 6). In fact, the resistance value for purified lanosterol (30 megohms x mfd.) at 105°C was still greater by a factor of two than the prescribed value for the high ambient temperature. Therefore, with respect to the properties mentioned in this section, the high ambient temperature of purified lanosterol capacitors could be extended to 105°C. Figures 2, 3 and 4 compare the electrical properties of these capacitors.

C. Dielectric Strength

The dielectric strength of paper-foil capacitors impregnated with the three varieties of the lanosterol impregnant was about 2500 volts per mil of paper thickness. This value did not change noticeably with temperature [11]. Very low temperatures appeared to have little effect on the magnitude of breakdown voltage, and the dielectric strength of lanosterol presented no limitation in its use as an impregnant for paper-foil capacitors. The addition of castor oil produced no change in the dielectric strength of lanosterol.

D. Capacitor Life

The life testing procedure followed the MIL-C-25 specifications. The testing voltage was 1.40 times the nominal voltage. A 250 hour life was required. Capacitors were tested at -55°C, +25°C and +85°C. For evaluation purposes it was decided to extend the test time at 85°C to 500 hours. The complete life test data are included in Progress Report #5.

The units which were selected on the basis of the life testing program as satisfactory for final designs are tabulated below. With one exception these designs exhibited no failures in 12 units at each of the test temperatures. The 200 volt unit impregnated with the mixture of 90% purified lanosterol and 10% castor oil had one failure in twelve during the room temperature life test. The result, however, is still within the life requirements of JAN-C-25.

Impregnant	Kraft Papers	Operating Voltage
Purified lanosterol	3 x 0.00020"	200 VDC
" "	3 x 0.00030"	600 VDC
90% Purified Lanosterol + 10% Castor oil	3 x 0.00020"	200 VDC
" "	3 x 0.00035"	600 VDC
Commercial lanosterol	3 x 0.00030"	600 VDC

There was one failure in a group of twelve capacitors impregnated with commercial lanosterol and tested at 25°C (Table 9). No additional life tests were run with this variety of capacitor.

One group of capacitors impregnated with purified lanosterol was tested at 125°C. There were no failures in this group of twelve units after 250 hours (Table 10).

E. Dielectric Absorption

Dielectric absorption of lanosterol impregnated capacitors was examined using available test equipment. The method utilized a standard polystyrene capacitor against whose absorption the test capacitor was compared [10]. Accordingly, the purified lanosterol dielectric and the lanosterol-castor oil mixture were compared with the standard impregnants, Halowax* and Vitamin Q*.

The build-up of voltage after discharging of lanosterol capacitors was twice that of Vitamin Q, and more than 1-1/2 times that of Halowax. The castor oil additive increased this build-up to three times that of Vitamin Q and twice that of Halowax. Thus, the lanosterol impregnants have shown a greater dielectric absorption than the standard impregnants Halowax and Vitamin Q [11].

* Trade Name

The test procedure was as follows:

1. The unknown capacitor was charged to 200 VDC simultaneously with the standard polystyrene capacitor. The charging time was 30 seconds.
2. Both capacitors were discharged. The differences in potential between the test capacitor and the standard capacitor were recorded after 5, 10, 30, and 75 second intervals.

SECTION VI - EVALUATION OF METALLIZED PAPER CAPACITORS

A. Design and Manufacture

The test sections were manufactured according to standard metallized paper construction procedure. They were assembled in cans and seals identical to those used for the paper-foil capacitors. The various types of test capacitors, which were designed to have a capacity of one microfarad, are listed below.

Code	Impregnant	Paper	Operating Voltage	Can Size
ML-2	Purified lanosterol	1 x 0.00035" Met'd	200 VDC	0.398 x 1-9/16"
ML-6	Purified lanosterol	1 x 0.00035" Met'd		
		1 x 0.00045" Kraft	600 VDC	0.670 x 2-1/8"
MC-2	90% Purified lanosterol + 10% castor oil	1 x 0.00035" Met'd	200 VDC	0.398 x 1-7/16"
MC-6	"	1 x 0.00035" Met'd		
		1 x 0.00045" Kraft	600 VDC	0.670 x 2-1/16"

B. Dielectric Strength

It was desired to determine the maximum voltage which could be applied to lanosterol impregnated metallized paper capacitors before degradation of their electrical properties occurred. Six capacitors of each variety listed in Section VI-A were used for the evaluation.

Voltages were applied to the capacitors through a series resistance of

10,000 ohms, and were increased by increments of 100 volts. After each step, the capacitors were checked for capacity, dissipation factor and insulation resistance. The test was conducted at room temperature.

The results of these measurements are recorded in Table 11. The peak voltage applied to these different capacitors before any degradation of electrical properties occurred is tabulated below. Above these voltages, the capacitors exhibited a sharp decrease in resistance, an increase in dissipation factor, and a noticeable loss in capacitance.

Type Capacitor	Operating Voltage	Peak Clearing Voltage
ML-2	200 V.D.C.	800 V.D.C.
MC-2	200 V.D.C.	700 V.D.C.
ML-6	600 V.D.C.	1900 V.D.C.
MC-6	600 V.D.C.	1600 V.D.C.

The capacitors impregnated with purified lanosterol withstood somewhat higher voltages than did those which were impregnated with the castor oil mixture.

It was determined from these data that a value of twice the nominal voltage would be satisfactory as the clearing voltage for the lanosterol metallized paper capacitors. These voltages were somewhat below the peak clearing voltage levels. All metallized paper capacitors were sparked in order to clear, or burn off, any weak spots or shorts. A series resistance of one ohm per volt limited the peak charging current to one ampere.

C. Variation of Electrical Properties With Temperature

The temperature characteristics of metallized paper capacitors met the requirements of MIL-C-25, Characteristic "F" (Table 12, Figures 6, 7, 8).

The addition of castor oil again caused a decrease in resistance throughout the temperature range. The metallized paper capacitors exhibited improved capacitance stability throughout the temperature range over that of the paper-foil capacitors.

D. Life Test Results

The life of a metallized paper capacitor is not normally terminated by the occurrence of a short circuit. It may be ended by an open circuit, a result which usually indicates imperfect construction. The customary limiting factor of the life of a metallized paper capacitor is degradation of insulation resistance. The Characteristic "F" limit is 1500 megohms x mfd. measured at room temperature. If the insulation resistance of a capacitor has dropped to less than one-thirds of this value (500 megohms x mfd.) after the life test, the unit is considered to have failed. A capacitor is also considered to have failed if a capacitance change of greater than 10% has resulted from the 85°C life test.

Groups of twelve units of each variety of metallized paper capacitors (Section VI-A) were life tested at 85oC. Groups were also tested at -55°C, +25°C and +125°C. The number of times that the capacitors shorted and cleared was recorded during the 85°C tests. These shorts were referred to as counts. The complete life test data are recorded in Table 17.

A summary of the life tests results is given in Table 13. With respect to the MIL-C-25 specifications, all groups passed the life tests. The 600 volt group which utilized the purified lanosterol impregnant exhibited a 14% drop in capacitance after the 25°C life test. Although there are no specifications for life at room temperature, this capacitance drop is undesirable for many capacitor applications.

No definite trends are indicated by the life test results. The addition of castor oil appeared to improve the capacitance stability of the lanosterol impregnant. However, this addition also produced a very large variation in insulation resistance measured after the life test.

The only failure occurred during the 125°C life test of the ML-2 group. The resistance of one unit dropped below the prescribed limit.

E. Current Characteristics

The effect of repeated high current surges on a metallized paper capacitor is important in many capacitor applications. Therefore, a test was performed to determine whether high current surges had a detrimental effect on lanosterol impregnated metallized paper capacitors. The test effectively checked the electrical connections to the electrodes of the capacitor. High dissipation factors and open connections would be the result of repeated current surges on an inadequately constructed unit.

The test capacitors were charged and discharged 100 times. The applied voltage was 2.0 x the nominal voltage. Some capacitors were charged with no current limiting device. The charging and discharging current was limited on other capacitors to a maximum of about one ampere by means of a resistor in series with the charging circuit. The dissipation factor was recorded after the units were charged 1 time, 10 times, 25 times, 50 times and 100 times.

The capacitors charged through a current limiting resistor exhibited no deterioration after the 100 applications of voltage (Table 14). One capacitor of the group charged with no current limiting resistor developed and open connection after 100 charges and discharges. This unit exhibited an increasing dissipation factor even after ten applications of voltage. All other capacitors of this group showed no deterioration at the end of the test (Table 14).

SECTION VII - THE MERITS OF LANOSTEROL CAPACITORS

A. Electrical Properties

Purified lanosterol was superior to both the commercial lanosterol and the lanosterol-castor oil mixture with respect to temperature characteristics. This superiority was less pronounced with metallized paper capacitors than with paper-foil capacitors (Figures 3 8).

The addition of castor oil to the lanosterol impregnant was not desirable from the temperature characteristic standpoint. However, the castor oil did produce an increase in the dielectric constant at room temperature.

Lanosterol impregnated capacitors exhibited an excessive loss in capacitance when maintained under stress at room temperatures. The addition of castor oil considerably reduced this capacitance loss, and thus increased the useful limit of operation of lanosterol capacitors. The capacitance changes of the various types of test capacitors are listed in Table 15.

The degree of capacitance loss incrsased with increases in the ratio of lanosterol to the other components in the dielectric (Table 15). Paper-foil capacitors contain ca. 35% impregnant, multipaper metallized capacitors contain ca. 30% impregnant, and single paper metallized capacitors contain from 20% to 25% impregnant. From this standpoint, the 200 volt metallized paper capacitor, which contained the smallest percentage of lanosterol, was the most desirable design. The property of capacitance loss appeared to be an inherent characteristic of the lanosterol dielectric.

This variation in the proportions of dielectric constituents also affected the temperature coefficient of capacitance. The capacitance loss at high temperatures increased with increasing percentages of lanosterol. Again, the 200 volt metallized paper capacitor, containing the smallest percentage of lanosterol, exhibited the least loss in capacitance at +125°C (Tables 8, 12). The dielectric constant of lanosterol drops off sharply at both temperature extremes. The dielectric constants of paper and lacquer drop off at the low temperatures, but increase from room temperature to +125°C. Thus, as expected, the variation of the proportion of lanosterol in the dielectric, caused only small changes in the capacitance loss at -55°C, but produced considerable variations of this property at high temperatures.

B. Capacitor Size

The most desirable effect of the application of lanosterol as a capacitor impregnant was an increase in capacitance. This was a result of the high dielectric constant of lanosterol. Table 18 offers a comparison of the sizes of lanosterol capacitors with capacitors utilizing standard impregnants. The comparisons were made in terms of capacitance per unit volume of the assembled unit (microfarads per cubic inch.

The 200 volt lanosterol impregnated metallized paper capacitor exhibited the greatest capacitance per unit volume. Of course, one of the advantages of metallized paper construction over paper-foil construction is a sizeable increase in capacitance, (especially for 200 volt units). A further size reduction of 25 to 60% resulted from the use of lanosterol instead of the standard mineral wax impregnant in metallized paper capacitors.

The size reduction of 600 volt lanosterol paper-foil capacitors over those utilizing Vitamin Q varied from 0% for very low capacities to 80% for capacities over 0.5 microfarads.

The size of lanosterol capacitors was greater than that of Halowax capacitors. Halowax has a fairly high dielectric constant. Furthermore, standard 200 volt Halowax paper-foil capacitors utilize less paper (0.5 mils) than do lanosterol capacitors. Thus, it is actually disadvantageous to replace the Halowax impregnant with lanosterol when a low voltage paper-foil capacitor is desired for no higher than 85°C operation.

CORRECTION TO

FINAL REPORT

Contract No. DA--36-039-sc-42485

PLEASE DELETE THE TWO PARAGRAPHS ON PAGE 26 AND INSERT THE FOLLOWING:

"those utilizing Vitamin Q ranged from 70 - 75%. Lanosterol capacitors were 20% smaller than Halowax capacitors."

-26-

SPRAGUE ELECTRIC COMPANY

NORTH ADAMS, MASSACHUSETTS

SECTION VIII - SAMPLE CAPACITORS

All sample capacitors were "inductively" wound. They were encased in metal cans hermetically sealed with glass-kovar end seals. The remaining design data is listed below for the nine types of samples produced.

A. Paper-foil Capacitors

	(1)	(2)	(3)	(4)	(5)
No. of Samples	25	25	25	25	12
Designation	S74021	S74020	S74023	S74022	S80580
Voltage	200 VDC	600 VDC	200 VDC	600 VDC	600 VDC
Capacity	2.8 mfd	1.4 mfd	0.016 mfd	.0068 mfd	1.0 mfd
Impregnant	Purified lanosterol				Commercial lanosterol
Kraft Papers					
Width	1 15/16"	1 15/16"	9/16"	9/16"	2 3/16
Thickness	3x0.00020"	3x0.00030"	3x0.00020"	3x0.00030"	3x0.00030"
Al. Foil					
Width	1 11/16"	1 11/16"	7/16"	9/16"	1 11/16"
Thickness	0.00025"	0.00025"	0.00025"	0.00025"	0.00025"
Margin	1/8"	1/8"	1/16"	1/8"	1/8"
Mandrel	1/8"	1/8"	5/64"	5/64"	1/8"
Turns	215	160	22 1/2	17 1/2	123
E. L. F.	332"	247"	8 1/2"	6 1/2"	158
Can Size					
Diameter	1.000"	1.000"	0.253"	0.253"	0.750"
Length	2 1/16"	2 1/16"	11/16"	11/16"	2 7/16"
Wire	#20	#20	#22	#22	#20
Al. Contacts	.0015x3/16"	.0015x3/16"	.0015x3/32"	.0015x3/32"	.0015x3/16"

B. Metallized Paper Capacitors

	(6)	(7)	(8)	(9)
No. of Samples	25	25	25	25
Designation	S76277	S76279	S76280	S76278
Voltage	200 VDC	200 VDC	200 VDC	200 VDC
Capacity	12.6 mfd	0.083 mfd	13.0	0.084 mfd
Impregnant	Purified Lanosterol		90% Purified Lanosterol + 10% Castor Oil	
Met'd Paper				
Width	1 3/4"	3/8"	1 3/4"	3/8"
Thickness	0.00035	0.00035	0.00035	0.00035
Margin	1/16"	1/16"	1/16"	1/16"
Mandrel	1/8"	0.04"	1/8"	0.04"
Turns	560	115	560	115
E. L. F.	908"	43 1/2"	908"	43 1/2"
Can Size				
Diameter	1.000"	0.235"	1.000"	0.235"
Length	2 1/16"	11/16"	2 1/16"	11/16
Wire	#20	#22	#20	#22

CONCLUSION

The main advantage in the use of lanosterol as a capacitor impregnant was one of size. Lanosterol impregnated capacitors were smaller by 20% to 50% than capacitors utilizing standard impregnants. The performance of lanosterol was comparable to that of other solid impregnants commonly employed in capacitors for 85°C operation.

The capacitors impregnated with lanosterol were capable of meeting the requirements of MIL-C-25, Characteristic "F". The three impregnants used were commercial lanosterol, purified lanosterol, and the mixture of 90% purified lanosterol plus 10% castor oil. Both paper-foil and metallized paper capacitors were manufactured. The type capacitor and/or impregnant most desirable for various electrical properties is listed below.

a. Insulation resistance vs. temperature--purified lanosterol impregnant.

b. Dissipation factor vs. temperature--purified lanosterol impregnant.

c. Capacitance change vs. temperature--200 volt metallized paper capacitor containing purified lanosterol.

d. Life--all combinations were satisfactory.

e. Dielectric strength--all combinations were satisfactory.

f. Capacitance stability (capacitors under stress at room temperature)-the 200 volt metallized paper capacitor containing the purified lanosterol-castor oil mixture.

g. Capacitance per unit volume--the 200 volt metallized paper capacitor containing the purified lanosterol-castor oil mixture.

From an overall standpoint the most desirable capacitor was a 200 volt metallized paper unit impregnated with the purified lanosterol-castor oil mixture. This unit coupled the advantages normally attributed to metallized paper capacitors with those of size and capacitance stability, properties of the particular impregnant.

At this time (December, 1953) lanosterol is not being produced commercially. Future availability, an economic consideration, is at present uncertain.

A P P E N D I X

HEADQUARTERS

SIGNAL CORPS ENGINEERING LABORATORIES

Fort Monmouth, New Jersey

SIGEL-SMB-cp
Project 2006
C01-Capacitors
Contract No. DA-36-039-sc-42485

Director
Squier Signal Laboratory, SCEL
Fort Monmouth, New Jersey

Sprague Electric Company
North Adams,
Massachusetts

Attention: Mr. G. Ceely, Assistant to the President

Gentlemen:

This will acknowledge your letter dated 17 October 1952 regarding Signal Corps Contract No. DA-36-039-sc-42485.

A review of the First Quarterly Report has been made, and it is recommended that the second phase of this development be started as soon as possible. In connection with this second phase, it is suggested that paper capacitors, both foil and metallized, be impregnated with Botany Mills lanosterol processed by the latest methods. It is further suggested that the material be heated in vacuum and held under vacuum prior to the impregnation of the capacitors. It is believed one of the difficulties in obtaining the higher dielectric constant is due to heating of lanosterol in air.

The Technical Requirements as written required that the capacitors meet Characteristic "E" of JAN-C-25. Based on results reported in the First Quarterly Report, the Technical Requirements are being changed to require that you meet Characteristic "F" of JAN-C-25 with the exception of the dissipation factor; 2% is satisfactory for this value. This change does not require a modification of the Contract since it is of a technical nature.

This change is found to be advantageous and in the best interest of the Government and is approved and authorized; provided, there will be (1) no delay in delivery resulting therefrom, and (2) no increase in total contract amount because of such change. Prior to taking any action under this authorization, you are required to acknowledge receipt and acceptance of this letter by signing the extra copy enclosed herewith and returning it to this office for forwarding to the Contracting Officer.

Very truly yours,

Vincent J. Kublin
Contracting Officer's
Technical Representative
Squier Signal Laboratory

Date_______________

Receipt and acceptance of the above letter are hereby acknowledged. The change authorized therein will not result in any delay in delivery and will not be used as a basis for a claim for any increase in price of the equipment or service involved.

SPRAGUE ELECTRIC COMPANY
Contractor

By_______________

C O P Y

BOTANY MILLS, INC.

Chemical Products Division
Passaic, New Jersey

April 15, 1953

Sprague Electric Company
North Adams, Massachusetts

Attention: Mr. Earl Peters
Research and Engineering Dept.

Dear Mr. Peters:

We regret to advise that generally-depressed business conditions in our industry have made it necessary to arrive at a decision to close down (for the time being at least) some of our Chemical By-Product activities.

Accordingly, and unfortunately, after this date, we will no longer be able to supply a number of the lanolin and keratin derivatives which we have until now been making available on a small scale.

Included among these is our "Botalan Base 138" - Lanosterol.

Should business conditions improve - or should outside financial assistance via government research and development contracts - or in some other fashion - become available, we will give our most earnest consideration to the possible resumption of these activities.

We greatly appreciate the interest which you have displayed and deeply regret the necessity of this action.

Yours very truly,

BOTANY MILLS, INC.

F. R. Haigh
Chemical Products Division

BOTANY MILLS, Inc.

CHEMICAL PRODUCTS DEPARTMENT

PASSAIC, N. J.

BOTALAN BASE No. 138

(Lanosterol)

OUTLINE:

BOTALAN BASE #138 (Lanosterol) is a unique chemical whose properties and applications until recently have been largely unexplored due principally to the lack of any production in quantity. Not a mixture, but a single chemical compound, pure lanosterol is obtained in the form of white crystals, having a melting point of 140° - 142°C. The crystals melt on the application of heat, and when cooled again yield a hard, solid, resin-like, semi-transparent, light amber colored material. The grade described in this brochure is essentially the above substance "contaminated" with small amounts of Cholesterol and Aliphatic Lanolin Alcohols*, and has a melting point of 138°C.

Uses visualized include those of a hard wax or resin. It is felt that lanosterol will be capable of replacing many waxes, rosin, natural resins, etc. in many applications—including varnish making materials, insulating materials, in waxes and polishes, as a plastic and in plastics. Cosmetic and pharmaceutical uses visualized would include the improving of emulsions, and imparting hardness and increased viscosity to formulations.

AVAILABILITY:

BOTALAN BASE #138 (Lanosterol) is now available in pilot plant quantities for experimentation and evaluation. Commercial production will be undertaken with sufficient industrial acceptance.

*Separate Data Sheet available.

BOTALAN BASE No. 138

(Lanosterol)

TECHNICAL DATA

DESCRIPTION:

Soft, granular, free-flowing, non-greasy, white, odorless material—stable in storage (not subject to rancidity, etc.)—commonly handled in multi-wall paper bags or fiber drums.

DERIVATION:

From lanolin, by hydrolysis and isolation (occurs nowhere else in nature).

COMPOSITION:

Approximately 95% (or better) Lanosterol, $C_{30}H_{49}OH$, molecular weight 426—"contaminants" being small %s of Cholesterol and Aliphatic Lanolin Alcohols.* (Agnosterol, $C_{30}H_{47}OH$ molecular weight 424, may sometimes be present in very small amount.) The completely pure product (snow white, but otherwise essentially the same in major chemical and physical properties) is also available.

Lanosterol is a triterpene alcohol derivative closely related to the amyrins (occurring in rubber latex) it is also related to the sterols through its parent compound, Phenanthrene. In fact, lanosterol was originally thought to be a sterol. The material contains one reactive and one inert double bond.

PROPERTIES:

Melting Point—138°C (completely pure product 140° - 142°C).

(On cooling, the melted material does not return to its original physical state. A very hard, brittle, resin-like, semi-transparent, light amber colored product is obtained. Some polymerization and resinification can be made to occur—the extent being (controllably) determined by time of heat and other factors. By dissolving in hot acetone solution and cooling, the crystalline form may be re-produced.)

Boiling Point .... (0.4 mm.) 240°C (undecomposed).
Iodine Value ....56 (Wijz) 170.5 (Dams).

BOTALAN BASE No. 138

(Lanosterol)

TECHNICAL DATA

PROPERTIES (Continued)

Solubilities:

Water	Insoluble.
Methyl Alcohol	Very Slightly Soluble.
Ethyl Alcohol	Very Slightly Soluble.
Aliphatic Hydrocarbons (viz. petroleum ether)	Very Slightly Soluble.
Aromatic Hydrocarbons (viz. benzol, toluol, xylol)	Freely Soluble Hot Slightly Soluble Cold.
Chlorinated Hydrocarbons (viz. ethylene dichloride, chloroform)	Freely Soluble.
Ketones (viz. acetone)	Freely Soluble Hot Slightly Soluble Cold.
Esters (viz. ethyl acetate)	Freely Soluble Hot Slightly Soluble Cold.

BOTALAN BASE #138 is a good emulsion-producing agent in its own right—generally yielding water-in-oil emulsions. It mixes readily and is compatible with most oils, fats, waxes (including mineral oils, paraffin wax, other petroleum products), surface active agents, etc. When blended into an established emulsion formula it frequently contributes to the stability of the emulsion.

ELECTRICAL PROPERTIES:

Dielectric constant—about 12. Wide temperature ranges have little effect. Low leakage factor. Mixture with 15% Castor Oil suggested for impregnating paper for capacitors.

SUGGESTED USES

For production of wax compositions by melting with materials such as Japan Wax, Stearic Acid, Ozokerite, Hydrofol Glycerides, rosin, other resins, etc. Resultant product may be softened with higher boiling petroleum solvents—or emulsified with water for "no-rub" type compositions.

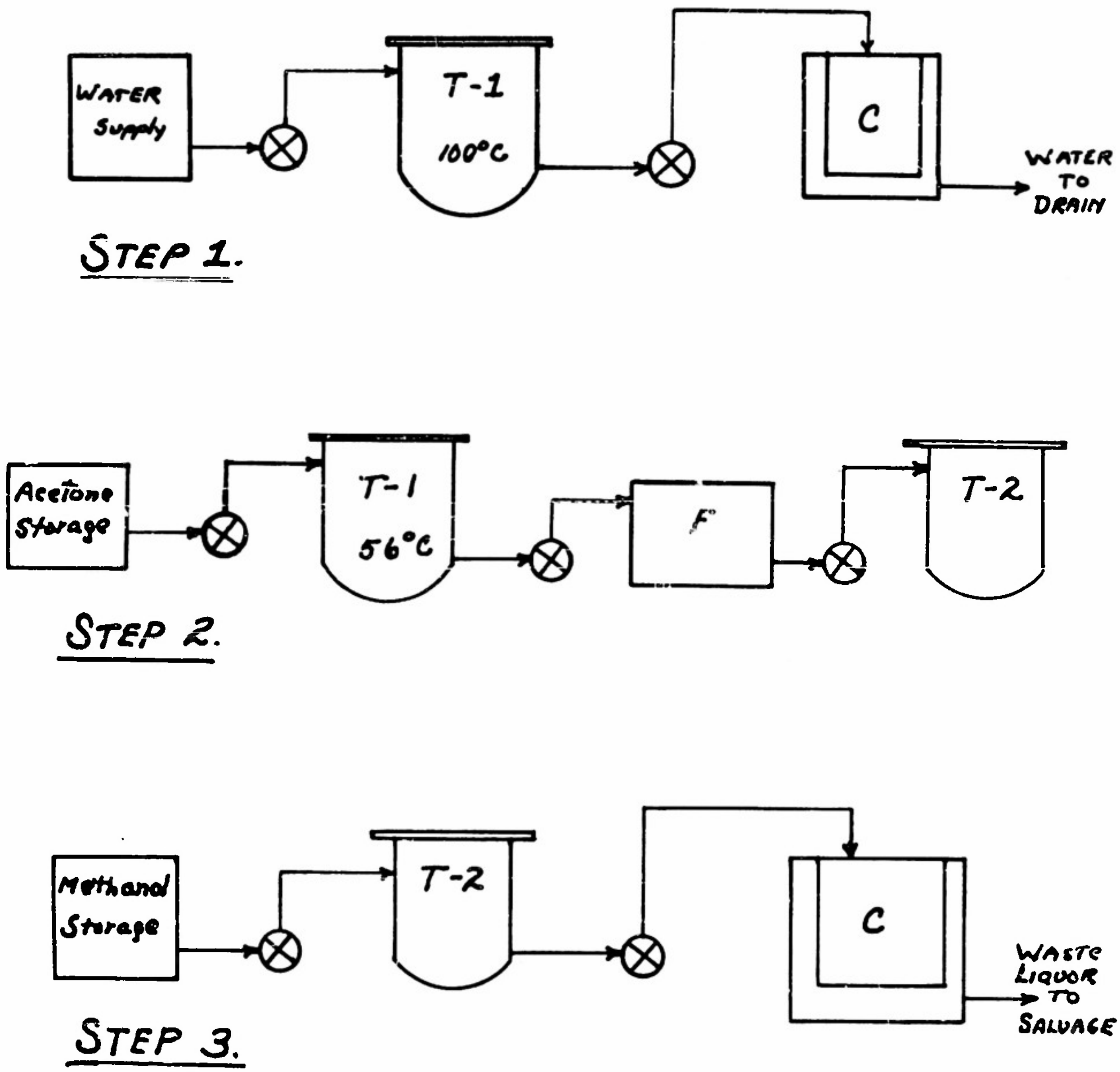
For electrical purposes—in insulating compounds, capacitors, batteries, transformers, etc.

For tablet coating.

In surface coatings—paints, varnishes, lacquers, etc.

In mold stripping.

In cosmetic and pharmaceutical formulations.



SYMBOLS

T-1 ... 250 gal. Steel Tank
T-2 ... 150 gal. glass-lined tank
C ... Stainless Steel Centrifuge
F ... Filter Press
⊗ ... Centrifugal Pumps

Figure 1

PILOT PLANT PROCESS FOR LANOSTEROL PURIFICATION

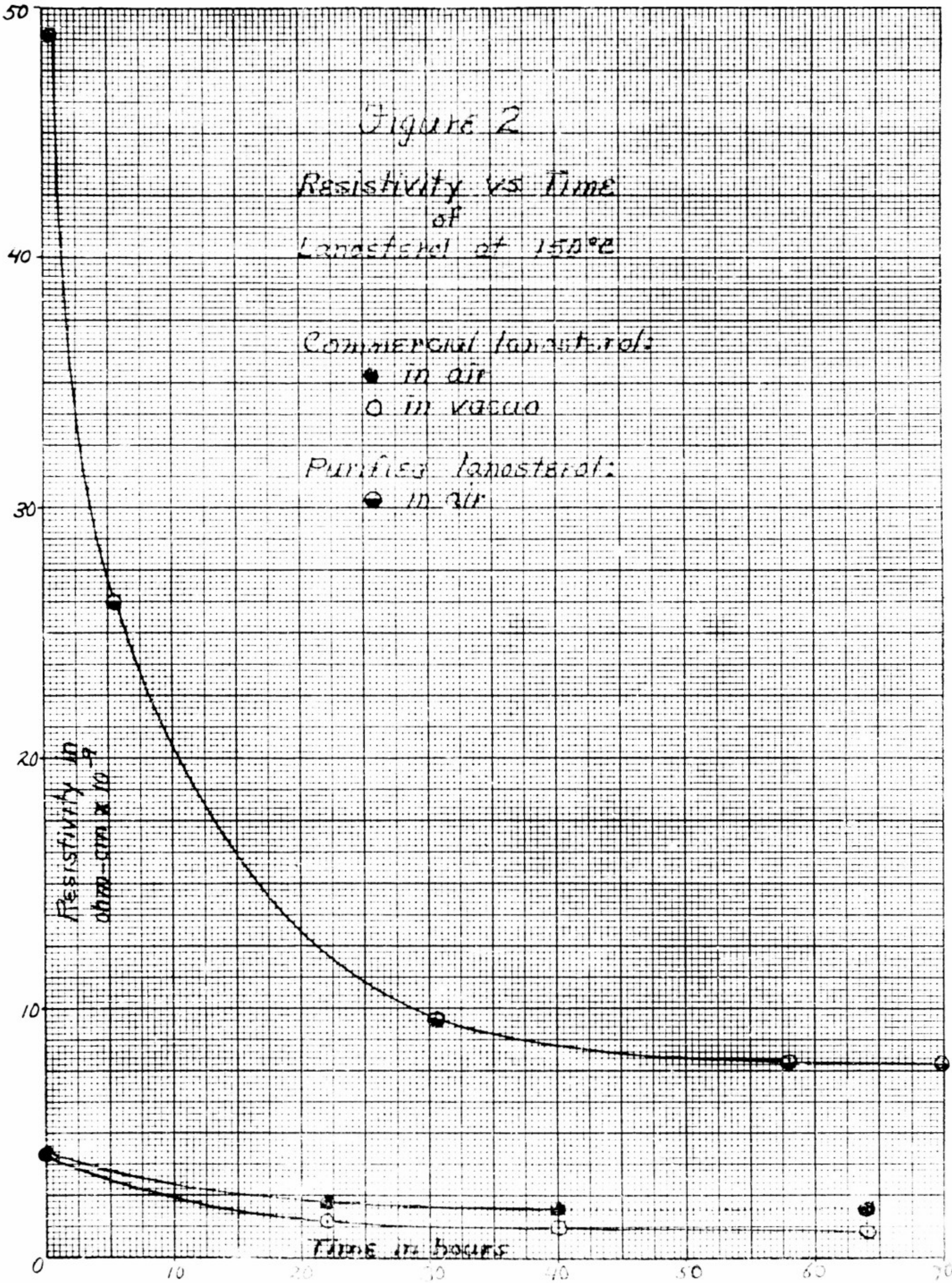


Figure 2
Resistivity vs Time of Lanosterol at 150°C
Commercial lanosterol:
in air
in vacuo
Purified lanosterol:
in air
Resistivity in ohm-cm x 10^9
Time in hours
0
10
20
30
40
50
60
70

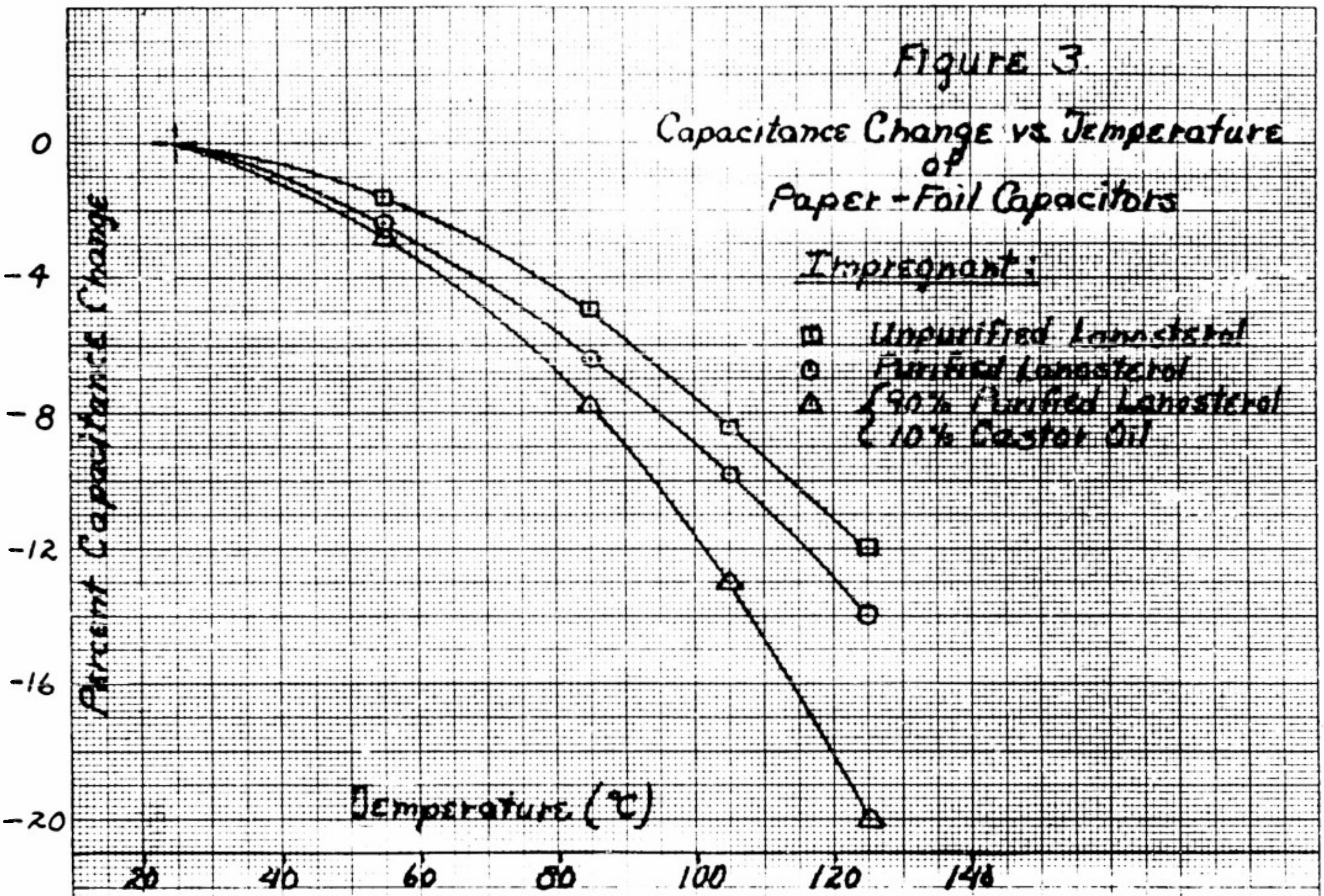


Figure 3
Capacitance Change vs. Temperature of Paper-Foil Capacitors
Impregnant:
Unpurified Lanosterol
Purified Lanosterol
90% Purified Lanosterol
10% Castor Oil
Percent Capacitance Change
Temperature (°C)
0
-4
-8
-12
-16
-20
20
40
60
80
100
120
140

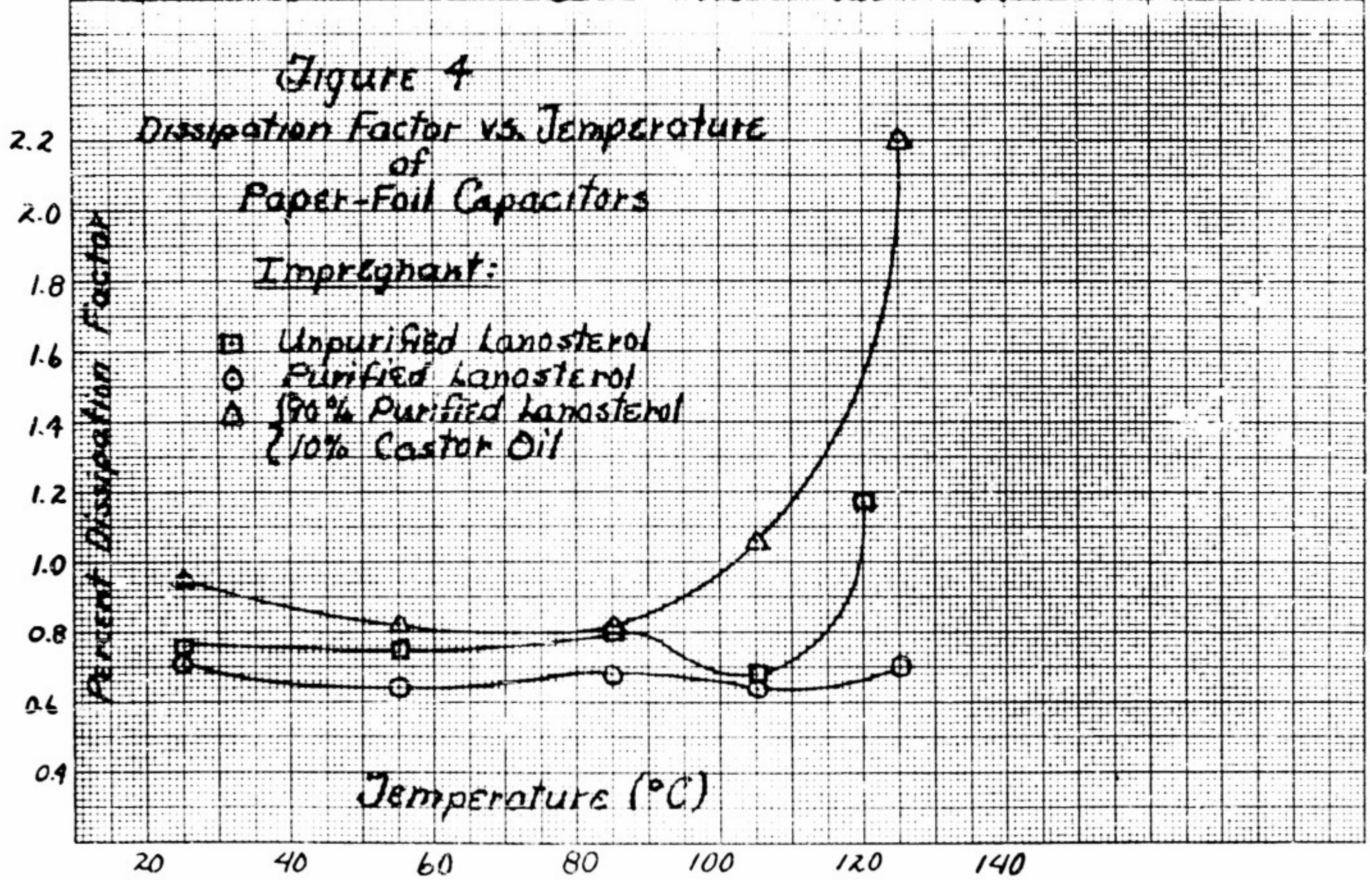


Figure 4
Dissipation Factor vs. Temperature of Paper-Foil Capacitors
Impregnant:
Unpurified Lanosterol
Purified Lanosterol
90% Purified Lanosterol
10% Castor Oil
Percent Dissipation Factor
Temperature (°C)
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
20
40
60
80
100
120
140

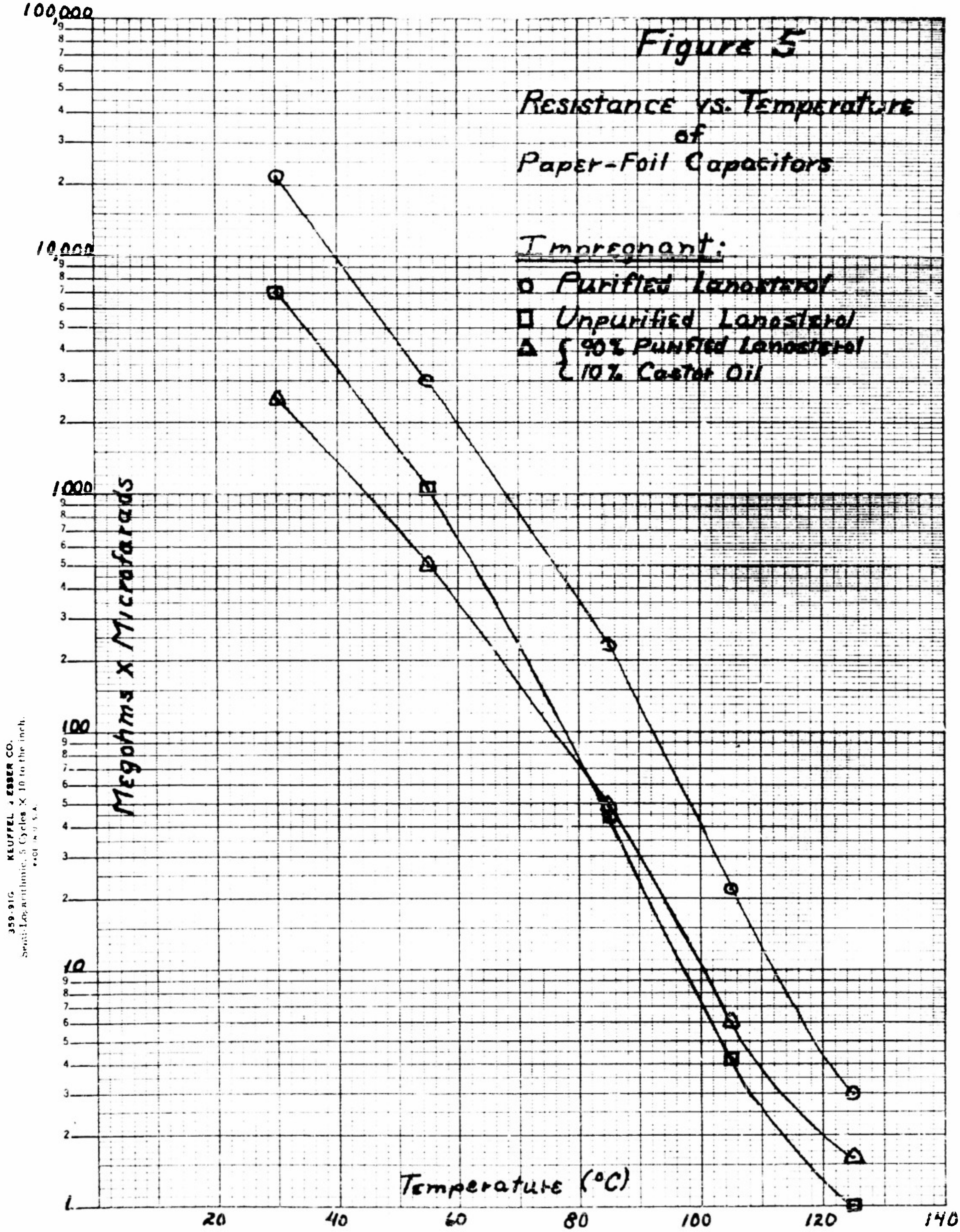


Figure 5
Resistance vs. Temperature
of
Paper-Foil Capacitors
Impregnant:
○ Purified Lanosterol
□ Unpurified Lanosterol
△ { 90% Purified Lanosterol
10% Castor Oil
Megohms X Microfarads
Temperature (°C)
100,000
10,000
1000
100
10
1.
20
40
60
80
100
120
140
359-91G KEUFFEL & ESSER CO.
Semi-Logarithmic, 5 Cycles X 10 to the inch.

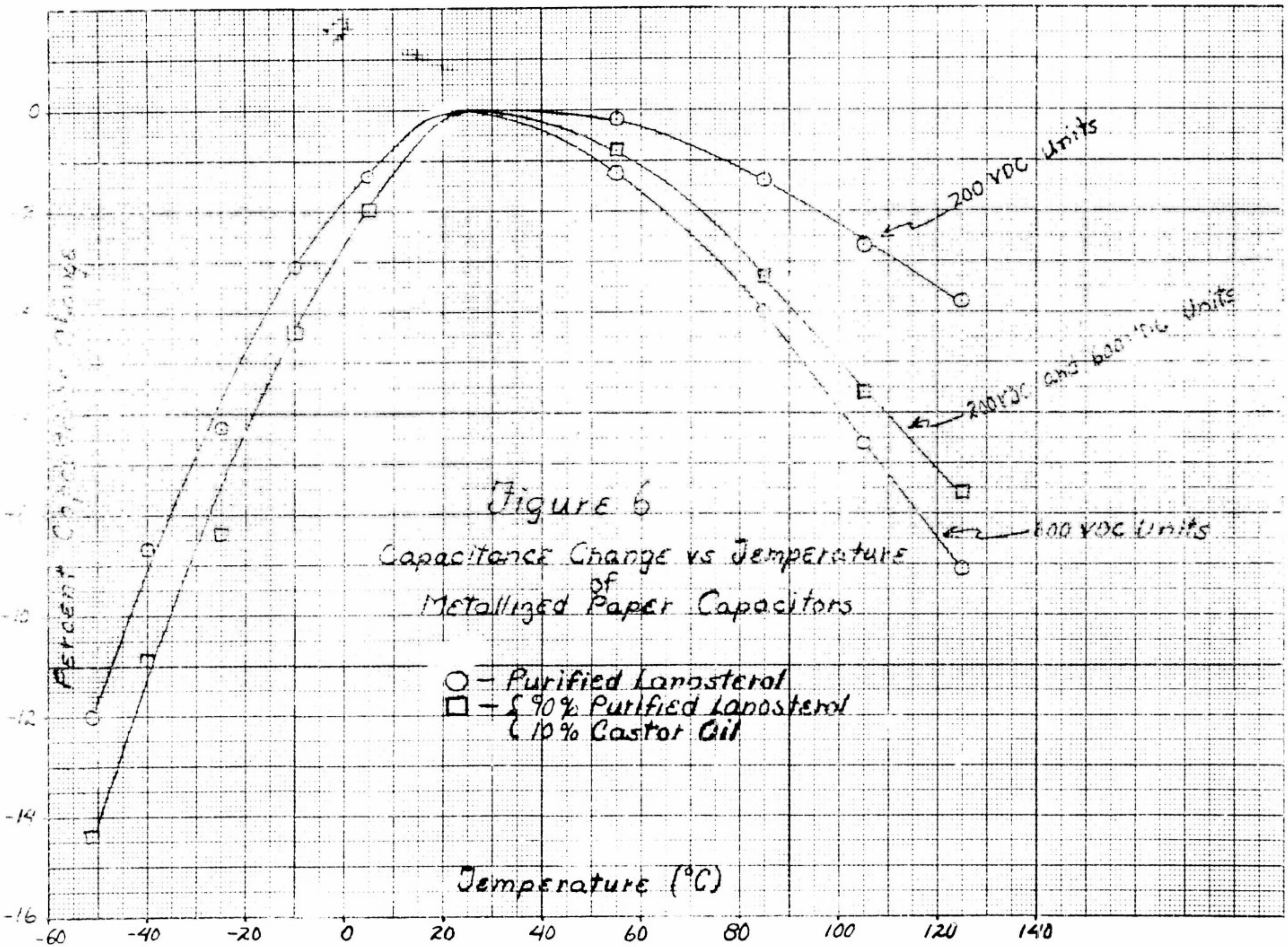


Figure 6

Capacitance Change vs Temperature of Metallized Paper Capacitors

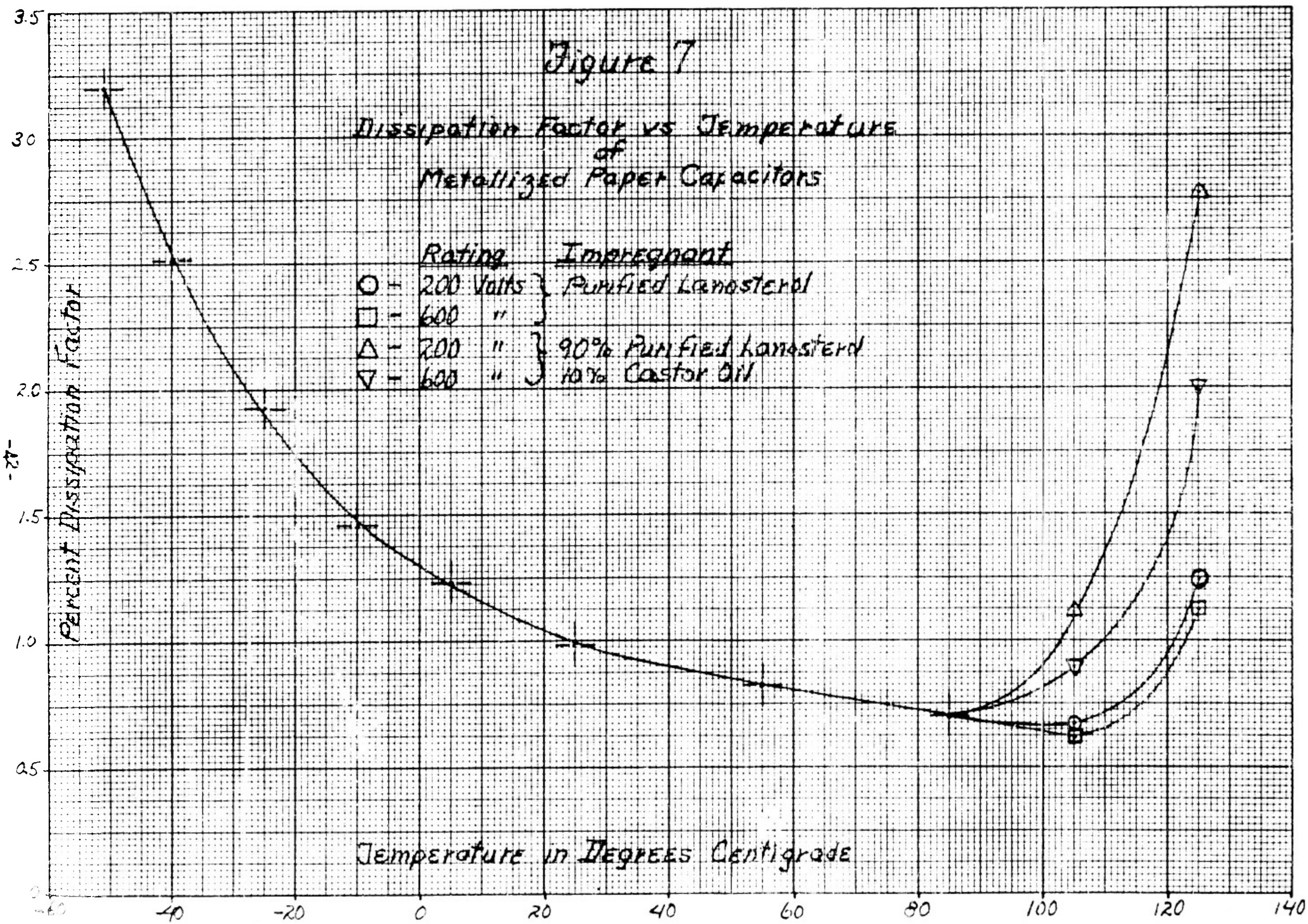


Figure 7
Dissipation Factor vs Temperature of Metallized Paper Capacitors
Rating Impregnant
○ - 200 Volts Purified Lanosterol
□ - 600 "
△ - 200 " 90% Purified Lanosterol
▽ - 600 " 10% Castor Oil
Percent Dissipation Factor
Temperature in Degrees Centigrade
3.5
3.0
2.5
2.0
1.5
1.0
0.5
-40
-20
0
20
40
60
80
100
120
140

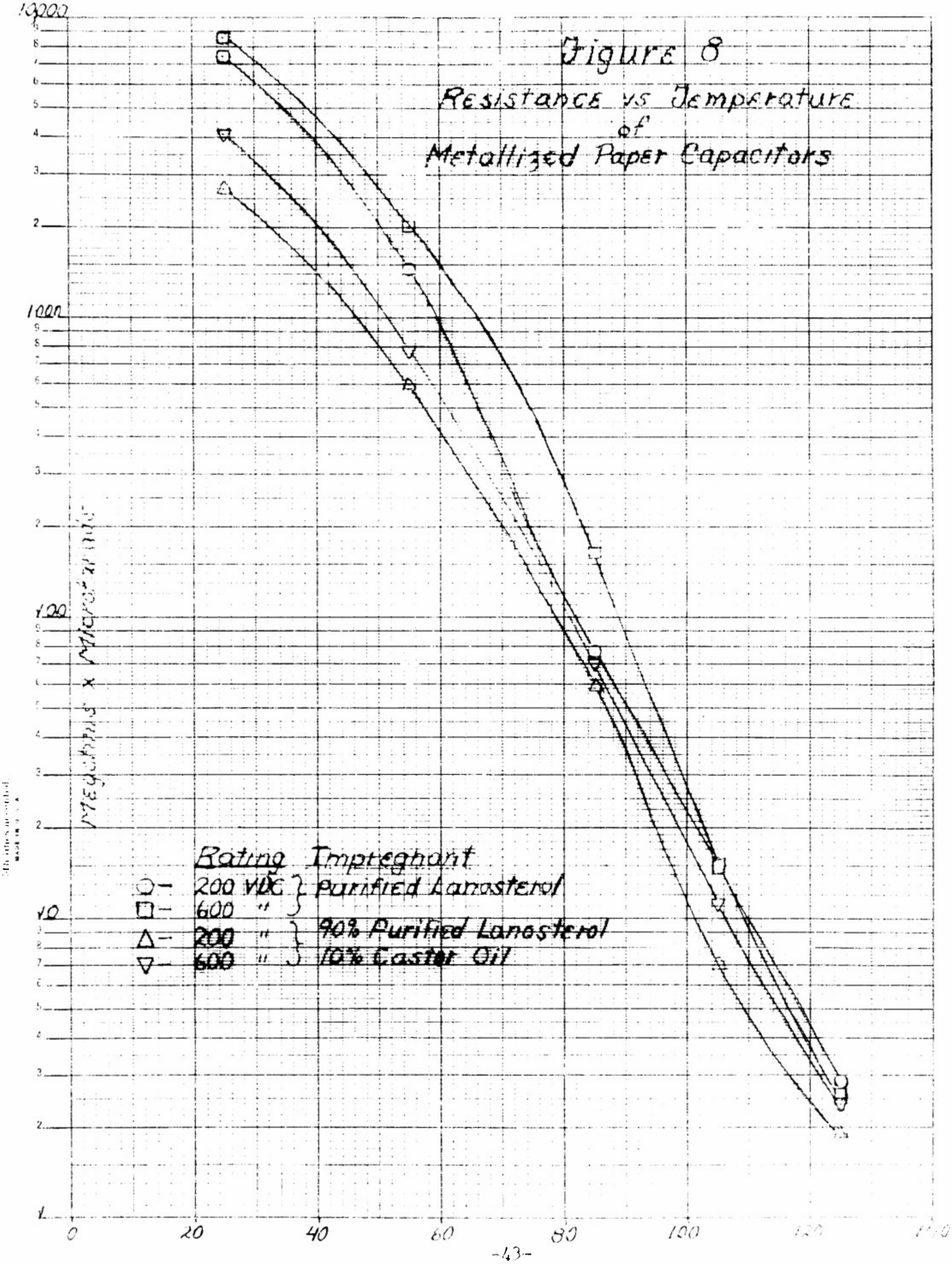


Figure 8
Resistance vs Temperature of Metallized Paper Capacitors
Megohms x Microfarads
Rating Impregnant
○ – 200 VDC } Purified Lanosterol
□ – 600 "
△ – 200 " } 90% Purified Lanosterol
▽ – 600 " } 10% Castor Oil
10000
1000
100
10
1
0
20
40
60
80
100
120
140

TABLE 1

Specific Gravity of Commercial Lanosterol

Temperature (°C)	Specific Gravity (t/20°)
20	1.033 1.018
50	0.992 0.998
80	0.963
150	0.934

TABLE 2

Viscosity of Commercial Lanosterol

Temperature in °C	Viscosity in centipoises
142	59
148	34
155	22
164	16
168	15
178	12
183	11

TABLE 3

Analytical Data

1. Saponification number (mg KOH per gram material)

   a. commercial lanosterol: 3.9, 5.1, 6.1, 7.4

   b. purified lanosterol: 2.9, 3.5, 3.6

2. Total acid number

   a. commercial lanosterol: 2.0, 2.1, 2.1

   b. purified lanosterol: 0.24, 0.24, 0.25

3. Ash content of commercial lanosterol

   Sample L-1: 0.20%

   L-2: 0.24%

   L-3: 0.22%

4. Analysis of water extract of commercial lanosterol

   a. first 2 hour extract;

      chloride: 2.5 ppm

      calcium and sulphate: traces

   b. second 2 hour extract;

      chloride: 1.2 ppm

      calcium and sulphate: traces

TABLE 4

Electrical Properties of Lanosterol

Purified by Various Methods

a. Commercial lanosterol.

b. Lanosterol: washed with water.

c. Lanosterol: recrystallized (retrol adsorbent).

d. Lanosterol: water washed, recrystallized (retrol adsorbent).

e. Lanosterol: water washed, recrystallized 3X (retrol adsorbent).

f. Lanosterol: adsorptively filtered with retrol.

g. Lanosterol: adsorptively filtered 3X with retrol.

h. Lanosterol: adsorptively filtered with Fuller's Earth.

i. Lanosterol: adsorptively filtered 3X with Fuller's Earth.

Temperature: 150°C

	Di-electric Const. at 1000 cycles	% Diss. Factor at 1000 cycles	Resistivity in ohm-cm at 180 VDC
a.	3.1	14	3.1×10^9
b.	2.99	8.2	5.5×10^9
c.	3.02	2.6	16×10^9
d.	2.85	2.0	25×10^9
e.	2.79	0.45	128×10^9
f.	2.90	4.2	27×10^9
g.	2.6	0.75	101×10^9
h.	3.05	5.5	6.3×10^9
i.	3.00	2.4	19×10^9

TABLE 5

Laboratory vs. Pilot Plant Purification

Lanosterol: washed with water, recrystallized in the presence of 10% retrol.

a. Laboratory purification

b. Pilot plant purification

Temperature: 150°C

	Di-elec. Const. at 1000 cycles	% Diss. Factor at 1000 cycles	Resistivity in ohm-cm at 180 VDC
a.	2.85	2.1	24.7×10^9
a.	2.85	2.0	24.5×10^9
b.	2.78	3.0	25.0×10^9
b.	2.82	3.2	24.0×10^9

TABLE 6

Comparison of Various Samples of Lanosterol

L-1: one pound sample received in early July 1952

L-2: 20 pounds received in late July 1952

L-3: 20 pounds received in September 1952

L-4: lanosterol received from Botany Mills in 1951

L-5: 140 pounds received in March 1953

Commercial Lanosterol	Temp. in oC	Di-elec.Const. at 1000 cycles	Resistivity in ohm-cm at 180 VDC	% Diss. Factor at 1000 cycles
L-1	154	3.1	8.0×10^9	8.2
L-2	153	3.1	5.9×10^9	11
L-3	150	3.1	3.1×10^9	14
L-4	152	3.3	7.3×10^9	8.8
L-5	150	3.1	1.5×10^9	30
Purified Lanosterol				
L-2	150	2.8	36×10^9	1.5
L-3	150	2.8	25×10^9	2.0
L-4	150	2.7	80×10^9	0.74
L-5	150	2.8	25×10^9	3.0

TABLE 7

The Slow Cooling Effect

Total cooling time: 153.5 hours

a. commercial lanosterol

b. lanosterol purified by recrystallization

c. lanosterol purified by repetitive (3X) adsorptive filtration

Temperature in °C	Dielectric Constant at 1000 cycles		
	a.	b.	c.
135	3.11	3.65	2.67
125	4.18	5.19	3.02
110	4.01	6.04	3.14
80	4.18	6.88	4.12
40	4.33	4.85	8.70

TABLE 8

Electrical Properties vs. Temperature

of

Paper-Foil Capacitors

Impregnants: UL - commercial lanosterol

L - purified lanosterol

C - 90% purified lanosterol +

10% castor oil

	25°C	55°C	85°C	105°C	125°C
	Resistance (megohms x mfd)				
UL	7,000	1,050	44	4.2	1
L	21,500	3,000	230	22	2
C	2,500	500	49	6	1.6
	% Dissipation Factor (1000 cycles)				
UL	0.76	0.75	0.82	0.68	1.17
L	0.71	0.64	0.68	0.64	0.70
C	0.95	0.82	0.80	1.06	2.2
	% Capacitance Change				
UL	0	-1.6	-4.9	-8.4	-12
L	0	-2.4	-6.4	-9.8	-14
C	0	-2.8	-7.8	-13	-20

TABLE 9

Life Test Results of Paper Capacitors

Impregnant: commercial lanosterol

Papers: 3 x 0.00030 Kraft

Rating: 1 mfd, 600 Volts

Temperature: +25°C

Test Voltage: 840 VDC

Test Duration: 250 Hours

Before Test			After Test			
Capacity (mfd at 60~)	Ins.Res. (meg-Ω)	Diss.Fact. at 60~	Capacity (mfd at 60~)	Ins.Res. (meg-Ω)	Diss.Fact. at 60~	Life (hours)
.94	10,000	0.5%	.79	10,000	0.5%	250
.93	"	"	.78	"	"	250
.94	"	"	.79	"	"	250
.96	"	"	----SHORT----			51
.96	"	"	.81	10,000	0.5%	250
.95	"	"	.80	"	"	"
.93	"	"	.79	"	"	"
.94	"	"	.79	"	"	"
.93	"	"	.79	"	"	"
.97	"	"	.81	"	"	"
.94	"	"	.79	"	"	"

TABLE 10

Life Test Results of Paper Capacitors

Impregnant: purified lanosterol
Papers: 3 x 0.00020 Kraft
Rating: 1 mfd, 200 Volts

Test Temperature: +125°C
Test Voltage: 280 VDC
Test Duration: 250 Hours

Before Test			After Test		
Capacity (mfd at 60~)	Ins. Res. (meg-at 25°C)	Diss.Fact. % at 60~	Capacity (mfd at 60~)	Ins. Res. (meg-at 25°C)	Diss.Fact. % at 60~
1.13	> 10,000	0.4%	1.12	> 10,000	0.4%
1.15	"	"	1.12	"	"
1.19	"	"	1.17	"	"
1.10	"	"	1.09	"	"
1.13	"	"	1.10	"	"
1.08	"	"	1.07	"	"
1.11	"	"	1.08	"	"
1.15	"	"	1.13	"	"
1.14	"	"	1.12	"	"
1.13	"	"	1.11	"	"
1.11	"	"	1.10	"	"
1.08	"	"	1.08	"	"

TABLE 11

Optimum Sparking Potential

of

Metallized Paper Capacitors

Temperature: $25^{\circ}C$ — Average of Six Readings

Taken at 1000 ∿

Voltage (volts.D.C.)	M C-2 Capacity (mfd)	M C-2 Diss.Fact. (%)	M C-2 Ins.Res. (Meg x mfd)	M L-2 Capacity (mfd)	M L-2 Diss.Fact. (%)	M L-2 Ins.Res. (meg x mfd)
200	0.858	0.91	1900	1.03	0.87	4100
300	.856	.89	2100	1.03	.87	5700
400	.857	.90	2000	1.03	.87	6900
500	.857	.89	2200	1.03	.94	6600
600	.856	.90	2000	1.03	.92	6100
700	.853	.90	2600	1.03	.87	5400
800	.846	1.01	2900	1.02	.85	5100
900	.758	1.34	170	1.02	1.04	3400
1000				1.00	1.90	1500

TABLE 11 (cont.)

	M C-6			M L-6		
Voltage (volts D.C.)	Capacity (mfd)	Diss.Fact. (%)	Ins.Res. (meg-Ω x mfd)	Capacity (mfd)	Diss.Fact. (%)	Ins.Res. (meg-Ω x mfd)
600	0.950	0.82	2800	0.948	0.73	6800
700	.950	.82	3000	.948	.69	6600
800	.950	.86	3600	.948	.68	6600
900	.950	.82	3000	.948	.68	5900
1000	.950	.81	2900	.947	.72	8200
1100	.950	.82	4100	.947	.71	7800
1200	.950	.86	4200	.947	.71	7800
1300	.950	.85	3400	.947	.71	7200
1400	.950	.81	2400	.946	.71	6800
1500	.950	.80	2500	.946	.70	7100
1600	.941	.82	2100	.946	.69	6800
1700	.934	.95	2600	.946	.70	7200
1800	.903	2.8	1400	.945	.70	6800
1900				.944	.72	5400
2000				.939	.73	4600
2100				.933	.75	5300
2200				.872	.91	2600

TABLE [illegible]

Temperature Characteristics of Metallized Paper Capacitors

(Average Values)

% D.F.: % dissipation factor at 1000 cycles

% Δ C: % change in capacitance from room temperature value

I.R.: insulation resistance in megohms x microfarads

	M L-2			M L-6		
Temp.	%D.F.	%Δ C	I.R.	%D.F.	%Δ C	I.R.
-51°C	3.22	11.6		3.27	12.4	
-40	2.62	8.6		2.51	8.8	
-25	2.12	6.2		1.98	6.4	
-10	1.56	3.2		1.34	3.0	
+5	1.38	1.4		1.06	1.2	
+25	0.99	0	7500	0.96	0	8600
+55	0.80	0.2	1450	0.72	1.25	2000
+85	0.71	1.4	77	0.70	4.0	165
+105	0.66	2.8	15	0.63	6.6	15
+125	1.24	3.8	2.8	1.12	9.1	2.5

TABLE 12 (cont.)

Temp.	M C-2 %D.F.	M C-2 %ΔC	M C-2 I.R.	M C-6 %D.F.	M C-6 %ΔC	M C-6 I.R.
-51°C	3.15	14.4		3.16	14.4	
-40	2.46	10.9		2.47	10.9	
-25	2.07	8.5		1.98	8.3	
-10	1.55	4.5		1.41	4.4	
+5	1.32	2.0		1.15	2.0	
+25	1.06	0	2700	0.93	0	4100
+55	0.86	0.8	600	0.74	0.8	770
+85	0.74	3.4	58	0.67	3.2	69
+105	1.11	5.8	7	0.89	5.4	11
+125	2.77	7.7	1.9	1.99	7.6	2.[illegible]

TABLE 13

Life Test Results of

Lanosterol Impregnated Metallized Paper Capacitors (Average Values)

Capacitance measured at 60 cycles. Resistance measured at 180 VDC for 2 min. at room temperature

Before Test

Temp.	Capacity (mfd)	Ins. Res. (meg-Ω x mfd)	Temp.	Capacity (mfd)	Ins. Res. (meg-Ω x mfd)
(ML-2)			(ML-6)		
-55°C	.97	9,700	-55°C	1.01	10,000
+25	.91	9,100	+25	.92	9,200
+85	1.07	11,000	+85	.98	9,800
+125	.90	9,000			
			(MC-6)		
(MC-2)			-55°C	.93	7,300
+25°C	.90	3,100	+25	.95	5,900
+85	.92	5,100	+85	.93	6,500

After Test

Temp.	Capacity (mfd)	Ins. Res. (meg-Ω x mfd)	Capacity Change	Res. Change	Percent Failures	Ave. No. Counts.
(ML-2)						
-55°C	.98	8,200	+1%	-14%	0%	
+25	.84	7,100	-8	-22	0	
+85	1.03	7,400	-4	-33	0	
+125	.91	8,600	+1	-5	8	
(MC-2)						
+25°C	.88	5,300	-2%	+71%	0%	
+85	.92	2,600	0	-50	0	1.9
(ML-6)						
-55°C	.99	9,900	-2%	-1%	0%	
+25	.79	7,900	-14	-14	0	
+85	.98	9,800	0	0	0	0.8
(MC-6)						
-55°C	.93	5,100	0%	-30%	0%	
+25	.92	8,500	-3	+44	0	
+85	.94	2,200	+1	-66	0	3.1

TABLE 14

Sparking Characteristics of Metallized Paper Capacitors

Capacity: mfd at 60 cycles

% D.F.: Percent dissipation factor at 60 cycles

Ins. Res. (I.R.); megohms after 2 minutes at 180 VDC

A. ML-2 Sparked at 400 VDC - no resistor

(Sparked 1x)			(10x)		(25x)		(50x)	
Cap.	%D.F.	I. R.	Cap.	%D.F.	Cap.	%D.F.	Cap.	%D.F.
0.92	0.65	11000	0.90	0.70	0.90	0.70	0.90	0.70
.88	.70	9000	.88	.75	.88	.65	.88	.70
.91	.70	15000	.91	.70	.91	.70	.91	.70
.90	.70	10000	.90	1.2	.90	1.2	.90	1.6
.87	.72	9000	.86	.70	.85	.65	.85	.70

(100x)		
Cap.	%D.F.	I. R.
0.91	0.65	14000
.88	.75	11000
.91	.65	16000
OPEN		
.85	.85	12000

TABLE 14 (cont.)

B. ML-2 sparked at 400 VDC - 550 ohm resistor

(Sparked 1x)			(10x)		(25x)		(50x)	
Cap.	%D.F.	I. R.	Cap.	%D.F.	Cap.	%D.F.	Cap.	%D.F.
0.87	0.65	14000	0.87	0.65	0.87	0.70	0.86	0.65
.87	.70	12000	.87	.65	.87	.80	.87	.70
.85	.70	13000	.85	.65	.85	.70	.85	.65
.90	.65	12000	.89	.70	.90	.75	.89	.65
.87	.60	12000	.87	.65	.87	.70	.86	.65

(100x)		
Cap.	%D.F.	I. R.
0.87	0.70	10000
.87	.70	14000
.85	.72	11000
.89	.70	11000
.86	.70	14000

TABLE 14 (cont.)

C. MC-2 sparked at 400 VDC - no resistor

(Sparked 1x)			(10x)		(25x)		(50x)	
Cap.	%D.F.	I. R.	Cap.	%D.F.	Cap.	%D.F.	Cap.	%D.F.
0.90	0.80	7000	0.90	0.85	0.90	0.85	0.90	0.85
.88	.90	6000	.87	.85	.87	.85	.87	.85
.89	.90	2600	.89	.85	.89	.90	.89	.85
.85	.80	7000	.85	.75	.85	.80	.85	.80

(100x)		
Cap.	%D.F.	I. R.
0.90	0.80	3700
.87	.85	3700
.88	.90	3400
.85	.95	5000

TABLE 14 (cont.)

D. MC-2 sparked at 400 VDC -- 550 ohm resistor

(Sparked 1x)			(10x)		(25x)		(50x)	
Cap.	%D.F.	I. R.	Cap.	%D.F.	Cap.	%D.F.	Cap.	%D.F.
0.88	0.85	6000	0.88	0.80	0.88	0.90	0.88	0.85
.91	.85	7000	.91	.80	.91	.80	.91	.85
.90	.85	2100	.90	.80	.90	.85	.90	.80
.90	.85	6000	.90	.85	.90	.80	.90	.82
.85	.82	7000	.85	.80	.85	.80	.85	.80

(100x)		
Cap.	%D.F.	I. R.
0.88	0.82	5000
.91	.85	5000
.90	.82	2400
.90	.80	5000
.85	.85	5000

TABLE 15

Variation in Capacitance of Capacitors

Conditions: 1.40 x rated voltage applied at room temperature for [illegible] hours.

Construction	Impregnant	Rating	Capacitance change
Paper-foil	purified lanosterol	200 VDC	-21%
Paper-foil	purified lanosterol	600 VDC	-1.6%
Paper-foil	commercial lanosterol	600 VDC	[illegible]
Paper-foil	90% purified lanosterol + 10% castor oil	200 VDC	[illegible]
Paper-foil	90% purified lanosterol + 10% castor oil	600 [illegible]	[illegible]
Metallized paper	purified lanosterol	200 VDC	[illegible]
Metallized paper and Kraft paper	purified lanosterol	600 VDC	-1.4%
Metallized paper	90% purified lanosterol + 10% castor oil	200 VDC	[illegible]
Metallized paper and Kraft paper	90% purified lanosterol + 10% castor oil	600 VDC	0%

TABLE 16

Sample Capacitors

Capacitance: measured at 60 cycles for values above 1 mfd
Diss. Factor: measured at 1000 cycles for values below 1 mfd

Ins. Res.: megohms after 2 minutes at 180 VDC

No. Samples	Type	Impregnant	Voltage Rating	Can Size	Capacitance (mfd)	Diss. Factor	Ins. Res. (megohms)
[illegible]	Paper-foil	purified lanosterol	200 VDC	0.235" x 11/16"	0.016	0.57%	> 10^5
25	Paper-foil	purified lanosterol	600 VDC	0.235" x 11/16"	.0086	0.59%	> 10^5
25	Paper-foil	purified lanosterol	200 VDC	1.000 x 2 11/16"	2.8	0.55%	3100
25	Paper-foil	purified lanosterol	600 VDC	1.000 x 2 1/16"	1.4	0.55%	8000
12	Paper-foil	commerc. lanosterol	600 VDC	0.750 x 2 7/16"	0.92	0.71%	3000
25	Metallized paper	purified lanosterol	200 VDC	0.235" x 11/16"	0.083	0.92%	10^5
25	"	90% purified lanos. 10% castor oil	200 VDC	0.235" x 11/16"	0.084	1.04%	40000
25	"	purified lanosterol	200 VDC	1.000 x 2 1/16"	12.6	0.80%	900
25	"	90% purified lanos. 10% castor oil	200 VDC	1.000 x 2 1/16"	13.0	0.90%	260

TABLE 17

Life Test Data of Metallized Paper Capacitors

Capacity (Cap.): mfd at 60 cycles
Diss. Factor (%D.F.): % at 60 cycles
Ins. Res. (I.R.): megohms after 2 minutes at 180 VDC

A. ML-2

Impregnant: purified lanosterol — Rating: 1 mfd, 200 VDC
Paper: 1 x 0,00035" metallized — Test Voltage: 280 VDC

Temperature: -55°C

Before Test			After 250 Hours		
Cap.	%D.F.	I. R.	Cap.	%D.F.	I. R.
0.91	0.60%	10000	0.91	0.60%	10000
1.07	"	"	1.07	"	2000
0.93	"	"	0.92	"	10000
1.07	"	"	1.07	"	10000
0.88	"	"	0.88	"	10000
1.06	"	"	1.05	"	7500
0.90	"	"	0.90	"	7500
0.92	"	"	0.91	"	7500
0.91	"	"	0.90	"	9000
0.94	"	"	0.94	"	10000
1.06	"	"	1.06	"	7500
1.03	"	2	1.03	"	10000

Temperature: +25°C

Before Test			After 250 Hours		
Cap.	%D.F.	I. R.	Cap.	%D.F.	I. R.
0.90	0.60%	10000	0.85	0.60%	10000
.91	"	"	.84	"	4500
.88	"	"	.84	"	6000
.88	"	"	.83	"	10000
.93	"	"	.84	"	10000
.91	"	"	.84	"	4000
.94	"	"	.88	"	4000
.93	"	"	.87	"	10000
.90	"	"	.84	"	10000
.92	"	"	.87	"	10000
.88	"	"	.83	"	10000
.90	"	"	.84	"	10000

TABLE [illegible] (cont.)

Temperature: +85°C

Before Test			After 250 Hours			
Cap.	%D.F.	I. R.	Cap.	%D.F.	I. R.	Counts
1.08	0.60%	10000	1.04	0.60%	9000	0
1.05	"	"	1.02	"	7500	"
1.05	"	"	1.02	"	4000	"
1.06	"	"	1.03	"	2000	"
1.07	"	"	1.03	"	9000	"
1.07	"	"	1.04	"	9000	"
1.05	"	"	1.02	"	9000	"
1.08	"	"	0.96	"	1000	"
1.08	"	"	1.04	"	9000	"
1.05	"	"	1.01	"	9000	"
1.08	"	"	1.06	"	9000	"
1.08	"	"	1.05	"	9000	"

Temperature: 125°C

Before Test			After 250 Hours		
Cap.	%D.F.	I. R.	Cap.	%D.F.	I. R.
0.90	0.6%	10000	0.92	0.8%	10000
.87	"	"	.90	"	"
.90	"	"	.91	"	"
.95	"	"	.96	"	"
.91	"	"	.93	"	"
.88	"	"	.90	"	"
.91	"	"	.91	"	"
.93	"	"	.93	"	"
.90	"	"	.91	"	"
.90	"	"	.91	"	"
.90	"	"	.90	"	"
.90	"	"	.91	"	220

TABLE 17 (cont.)

B. ML-6

Impregnant: purified lanosterol
Paper: 1 x 0.00045 Kraft
1 x 0.00035 Metallized

Rating: 1.0 mfd, 600 VDC
Test Voltage: 840 VDC

Temperature: -55°C

Before Test			After 250 Hours		
Cap.	%D.F.	I. R.	Cap.	%D.F.	I. R.
0.98	0.5%	10000	0.98	0.5%	10000
1.01	"	"	1.01	"	"
1.01	"	"	1.01	"	"
1.02	"	"	1.01	"	"
0.93	"	"	0.93	"	"
1.01	"	"	1.01	"	"
0.95	"	"	0.95	"	"
1.02	"	"	1.02	"	"
1.04	"	"	1.03	"	"
1.02	"	"	1.02	"	"
0.93	"	"	0.93	"	"

Temperature: 25°C

Before Test			After 250 Hours		
Cap.	%D.F.	I. R.	Cap.	%D.F.	I. R.
1.00	0.5%	10000	0.84	0.5%	10000
0.99	"	"	.84	"	"
0.98	"	"	.84	"	"
1.01	"	"	.87	"	"
0.97	"	"	.84	"	"
0.82	"	"	.71	"	"
0.85	"	"	.73	"	"
0.81	"	"	.71	"	"
0.84	"	"	.73	"	"
0.83	"	"	.71	"	"
0.98	"	"	.84	"	"

TABLE 17 (cont.)

Temperature: 85°C

Before Test			After 250 Hours			
Cap.	%.D.F.	I. R.	Cap.	%D.F.	I. R.	Counts
1.0	0.5%	10000	0.99	0.5%	10000	2
0.98	"	"	0.98	"	"	0
0.94	"	"	0.94	"	"	0
0.99	"	"	0.98	"	"	0
0.93	"	"	0.93	"	"	0
0.98	"	"	0.98	"	"	1
1.01	"	"	1.01	"	"	2
0.99	"	"	0.99	"	"	2
0.98	"	"	0.99	"	"	2
0.99	"	"	0.99	"	"	0
0.99	"	"	0.99	"	"	1
1.01	"	"	1.01	"	"	0

TABLE 17 (cont.)

C. MC-2

Impregnant: 90% purified lanosterol
10% castor oil
Paper: 1 x 0.00035" metallized

Rating: 1 mfd, 200 VDC
Test Voltage: 280 VDC

Temperature: +25°C

Before Test			After 250 Hours		
Cap.	%D.F.	I. R.	Cap.	%D.F.	I. R.
0.91	0.70%	2400	0.90	0.75%	2500
.88	"	3000	.85	"	7500
.90	"	3400	.89	"	3800
.87	"	3400	.84	"	7000
.91	"	3800	.90	"	8000
.93	"	3800	.91	"	7500
.90	"	3400	.88	"	5500
.90	"	3400	.88	"	8000
.92	"	3400	.91	"	6000

Temperature: +85°C

Before Test			After 250 Hours			
Cap.	%D.F.	I. R.	Cap.	%D.F.	I. R.	#Counts
0.90	0.70%	5500	0.89	0.70%	3000	3
.93	"	5500	.93	"	2800	1
.89	"	5500	.90	"	3000	1
.93	"	6000	.93	"	2800	1
.87	"	6000	.88	"	2600	11
.98	"	4500	.98	"	3000	0
.89	"	5500	.91	"	3000	2
.88	"	5500	.89	"	3000	0
1.01	"	5500	1.01	"	2100	1
0.89	"	5500	0.89	"	2800	0
.88	"	5500	.89	"	2600	2
.93	"	5500	.93	"	2600	1

TABLE 17 (cont.)

D. MC-6

Impregnant: 90% purified lanosterol
10% castor oil

Papers: 1 x 0.00035" metallized
1 x 0.00045" Kraft

Rating: 1 mfd, 600 VDC

Test Voltage: 840 VDC

Temperature: -55°C

Before Test			After 250 Hours		
Cap.	%D.F.	I. R.	Cap.	%D.F.	I. R.
0.91	0.70%	7500	0.91	0.70%	5500
.90	"	"	.90	"	5500
.97	"	"	.96	"	6000
.92	"	"	.93	"	5500
.95	"	"	.95	"	5500
.97	"	"	.96	"	4500
.96	"	"	.96	"	4500
.96	"	"	.95	"	5500
.90	"	"	.90	"	6000
.90	"	"	.89	"	7500
.93	"	"	.93	"	6000
.93	"	"	.93	"	6000

Temperature: +25°C

Before Test			After 250 Hours		
Cap.	%D.F.	I. R.	Cap.	%D.F.	I. R.
0.99	0.60%	6000	0.94	0.70%	10000
1.08	"	6000	1.03	"	6000
0.92	"	6000	0.88	"	10000
.93	"	6000	.89	"	10000
.94	"	1300	.90	"	3800
.93	"	5500	.90	"	10000
.92	"	6000	.90	"	10000
.94	"	7500	.91	"	10000
.94	"	7500	.91	"	10000
.93	"	6000	.90	"	10000
.92	"	7500	.91	"	10000
.95	"	6000	.91	"	10000

TABLE 17 (cont.)

Temperature: +85°C

Before Test			After 250 Hours			
Cap.	%D.F.	I. R.	Cap.	%D.F.	I. R.	# Counts
0.90	0.60%	7500	0.91	0.70%	2600	0
.94	"	7500	.94	"	2200	3
.95	"	6000	.95	"	2000	0
.92	"	6000	.93	"	2400	5
.89	"	7500	.89	"	2200	13
1.08	"	6000	1.09	"	2300	1
0.93	"	7500	0.93	"	2600	3
.90	"	7500	.91	"	2400	2
.89	"	7500	.91	"	2000	2
.01	"	7500	.92	"	2200	0
.95	"	6000	.96	"	2400	5

TABLE 18

Comparison of Capacitor Sizes

Impregnant	Voltage Rating	High Ambient temperatures	Microfarads per Cubic Inch: Capacitors below 0.1 mfd	Microfarads per Cubic Inch: Capacitors above 0.5 mfd
(Paper-foil Capacitors)				
Halowax	200 VDC	+85°C	1.1	2.2
Purified Lanosterol	200 VDC	+85°C	0.5	1.7
Vitamin Q	600 VDC	+125°C	0.2	0.5
Purified Lanos.	600 Vdc	+85°C	0.2	0.9
(Metallized Paper Capacitors)				
Mineral Wax	200 VDC	+85°C	2.2	4.9
Purified Lanosterol	200 VDC	+85°C	2.8	7.8
90% Purif. Lanos. 10% Castor oil	200 VDC	+85°C	2.8	8.0

BIBLIOGRAPHY

1. Vatermcdt et al, U. S. Patent 2,579,98[illegible] [illegible] 1951

   " " " 2,598,468 27 May 1952

2. Doree, McGhie, Kurzer, J. Chem. Soc., 1457 et al, (1947)
3. Voser, Guenthard, Yeger, and Ruzicka, Helv. Chim. Acta., 35, 66-75, (1952)
4. Voser, Yeger and Ruzicka, Helv. Chim. Acta., 27, 472, (1944)
5. Doree, McGhie, Kurzer, J. Chem. Soc., Suppl. Issue No. 1, S167-9, (1949)
6. Sulzberger and Lazer, Investigative Dermatology, 15, 453-458, (1950)
7. Progress Report #1
8. " " #2
9. " " #3
10. " " #4
11. " " #5
12. McMahon and Kohman, "Lanosterol - A New High Constant Dielectric", delivered before the AIEE meeting on 25 January 1952